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ON A CALIFORNIA ROOFING SLATE OF IGNEOUS ORIGIN.[1]

DURING the field season of 1903 the writer was enabled to spend several days in the study of the important roofing-slate deposits occurring north of Placerville, El Dorado county, California. A summary of the principal economic results of this investigation will soon appear in a bulletin[2] of the United States Geological Survey; while a more detailed description, with maps, will probably be issued later as one chapter in a Survey bulletin on the slate deposits of the United States.

One result of the study, however, would seem to be of sufficient novelty and general geologic interest to be worthy of discussion in this JOURNAL, in considerable detail. This is the determination that a part of the roofing slates of the El Dorado county district have been derived, by dynamic metamorphism, from basic igneous rocks—gabbros or related types.

THE CALIFORNIA SLATE DEPOSITS IN GENERAL.

Location and general relations.—Though roofing slate has at different times been quarried, on a small scale, in other parts of the state, the only important slate-producing area in California is located in El Dorado county. The quarries which have been opened in this district are located along a line running about N. 15° W. from Placerville, at distances of from one to six miles from that town. The location and general relations, both geographical and geological, of the slate deposits and quarries, can best be understood by reference to the maps included in the "Placerville Folio" of the United States Geological Survey. The workable roofing-slate deposits of this district occur in a belt of the Mariposa slates, of late Jurassic or early Cretaceous age. The quarries which have been opened are all situated near the western boundary of this belt of Mariposa slates, where it is bordered by a large area of diabase. This diabase has been described[1] by Lindgren and Turner as being "of the age of the Mariposa slates, or older." A number of linear areas of amphibolite occur in the Mariposa slates. These amphibolites are described as being derived from diabase or gabbro. They are in part altered to serpentine.

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[1] Published by permission of the director of the U. S. Geological Survey.

[2] *Contributions to Economic Geology*, 1903.

Previous work on the slate deposits.—The "Placerville Folio," No. 3, U. S. Geological Survey, published in 1894, contains the results of detailed geologic work by Lindgren and Turner in the area in which the roofing-slate deposits occur. At that date the roofing-slate industry had not assumed its present importance, though all the quarries now in existence had then been opened. The existence of roofing-slate deposits is noted in the text of the folio, and the locations of the quarries are indicated on the map showing the economic geology of the area. No reference is made to the "green slates," or to the dikes cutting the Eureka quarry.

Excellent, though brief, descriptions of the different quarries and of the condition of the slate industry at various dates are to be found in the *Reports of the State Mineralogist of California;* particularly in the eighth and twelfth reports.

At present the most important quarry is that of the Eureka Slate Co., and this is now being worked on a large scale. This quarry is located at Slatington, about one-half mile southwest from the point where Kelsey is shown on the Placerville atlas sheet.

Structural relations in Eureka quarry.—The cleavage planes of the slates in the Eureka quarry strike N. 25° W. The dip of the cleavage is practically vertical, with slight local variations to 80° E. or 80° W. The upper weathered beds in the quarry are overturned, by local pressure, so as to give 40° to 60° dips to the east or west, according to local conditions. This overturning is evidently due merely to the weight of the overlying soil and decomposed slate, and the effects are shown only for a depth of from 3 to 15 feet. It is of interest, however, as a warning against accepting dip readings taken from surface beds of the slate.

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[1] "Placerville Folio," U. S. Geological Survey; legend of "Areal Geology" sheet.

The slate body shows rather frequent, but narrow, "ribbons." These ribbons are bands (from $\frac{1}{16}$ to $\frac{1}{2}$ inch thick usually, but occasionally as thick as two inches) of material differing in composition from the mass of the slate. They are in general more siliceous than the normal slate, and do not furnish merchantable material. Their geologic interest arises from the fact that they represent differences of original sedimentation. The plane of the ribbons in a slate quarry is therefore the plane of original bedding. In the Eureka quarry, and, indeed, throughout the roofing-slate belt, the plane of original bedding seems to be usually within ten degrees of the plane of slaty cleavage.

The slate mass is cut by a series of joints, *parallel* to the "grain" of the slates, striking N. 55° E., and dipping from 70° to 80° to the northwest. Joints *across* the "grain" of the slate, which would be practically horizontal, do not occur in this quarry; but many of the thin quartz seams occupy this position.

Quartz and calcite occur in thin layers, filling joint spaces and occasionally cleavage spaces. Pyrite also occurs in very much flattened nodules, which were apparently parallel to the original bedding.

Character of the normal slate.—The mass of the Eureka quarry product is a dense, deep black slate, splitting very finely and regularly, with a smooth glistening surface much like that of the Bangor and Lehigh slates of Pennsylvania. The frequency of the ribbons, and of the pyrite nodules, prevents the slate from being serviceable as mill stock; but as a roofing material it is very satisfactory.

A specimen of the black slate, free from ribbon, was selected for analysis in the laboratory of the U. S. Geological Survey. The results of this analysis, by Mr. W. T. Schaller, follow:

ANALYSIS OF BLACK SLATE, EUREKA QUARRY, SLATINGTON, CALIF.

Silica (SiO_2)	63.52
Alumina (Al_2O_3) and titanic oxide (TiO_2)	16.34
Iron oxides (FeO, Fe_2O_3)	6.79
Lime (CaO)	0.98
Magnesia (MgO)	2.50
Carbon dioxide (CO_2) Water	4.86

THE "GREEN SLATES."

Appearance and structural relations.—Perhaps the most striking feature of the quarry of the Eureka Slate Co., as seen from the old ground surface eighty feet above the present floor of the quarry, is a light green band, four feet or so in width, that extends vertically from top to bottom of the quarry, and is particularly noticeable on the higher east wall. This band furnishes the "green slate" of the quarry men. The contrast in color between this green band and the intense black of the fresh surface of the rest of the slate is very striking.

Viewed from the old ground level, one cannot determine whether the green band is parallel to the slaty cleavage or to original bedding; which planes, as noted earlier in this paper, commonly differ only by ten degrees or so. At first sight, therefore, the green band might reasonably be considered to be a mere color variation, due either to original differences in composition of the beds from which the green and black slates were derived, or to a later change in the color of certain beds; and this view has apparently been accepted by former observers.

Closer study, however, removes this easy explanation from the list of possibilities. Even a casual examination of a green slate quarried from this band, and comparison with a slate of the normal black type, are sufficient to prove that the two slates are different in more than color; while a closer examination of the character and structural relations of the green band, when seen from the quarry floor below, suffices not only to emphasize the distinction between the green slate and the black, but to suggest a somewhat novel origin for the former.

Relations of contact plane to cleavage and bedding.—On going down into the quarry and closely examining the relations of the two slates, the contact between the green and black slates is seen to be, not parallel to the "ribbon" of the black slate, which indicates the plane of original bedding, but cutting the ribbon at a small angle—not over ten degrees. It is not, however, certain that the contact plane is exactly parallel to the plane of slaty cleavage, which also cuts the bedding plane at a small angle. This detail—the relation of the contact line to the cleavage planes—has, of course, no bearing on the question of the derivation of the green slates. It may prove, however, to be of some importance in determining the probable cause of the origin of slaty cleavage in this particular portion of the Mariposa slate belt.

Disregarding this omission of data as to the relation of contact to cleavage plane, the fact remains that the band of green slate is not everywhere conformable to the original bedding of the Mariposa slate series. It is, therefore, highly improbable that it was an originally interbedded member of that sedimentary series; on structural grounds it is probable that it represents a mass of igneous rock, injected as a dike into the Mariposa series and, subsequently to its intrusion, so highly sheared as to have a very perfect slaty cleavage. This probability is increased when the chemical composition of the rock is considered.

Further confirmation of this hypothesis is afforded by an examination of the cross-section of the dike, which proves that it is not homogeneous in texture throughout, but that it varies in bands closely parallel to the contact plane. Along its contact with the normal black slate, the green slate is very fine-grained for an inch or so. Bordering this is a zone several inches in width, of coarser texture, and drab-green color, which is followed in turn by the typical "green slate." These differences in color and texture are sufficiently noticeable to be readily distinguishable by the quarry men and slate splitters. The textural differences are such, in fact, that the layer immediately next to the contact is discarded as a "ribbon," since it works unsatisfactorily. It must be recollected, however, that these layers are parallel to the contact, not to the "ribbon" or original bedding of the black slate.

Igneous rocks of the vicinity.—About five hundred feet west of the present quarry the western edge of the Mariposa slate is reached, a body of igneous rock limiting it in that direction. This rock is described in the "Plàcerville Folio" as diabase. A linear outcrop of amphibolite, trending about parallel with the cleavage of the slates, is shown on the "Areal Geology" sheet of this folio, near Kelsey, and some distance east of the Eureka quarry. Other amphibolite dikes occur to the north and south of Kelsey.

Several other dikes, not hitherto mapped, and important in their bearing on the problem of the origin of the green slates, were noted during the recent work. These dikes outcrop between the quarry and the diabase body west of it, as narrow linear areas, trending N. 25° W., or thereabout. They are best shown, however, in a tunnel which is now being driven for drainage and working purposes. This tunnel starts in the Kelsey ravine, which marks the boundary between the diabase and the Mariposa slates; and runs eastward to the quarry, coming in at about twenty feet below its present floor level.

This tunnel intersects three dikes, in addition to cutting the green band of the quarry. Of these dikes, two show material which is fairly massive, while the third, the one nearest to the green band, seems to have a decidedly slaty structure, though not sufficiently so as to be utilized as a source of roofing slate. From these observations it would seem that the intensity of the shearing, which resulted in the present slaty cleavage, increased as did the distance from the contact of the Mariposa slate and the diorite.

Microscopic investigation.—The results of microscopic investigation were of no particular service in this connection, owing to the fact that sufficient fresh material had not been secured from the various dikes.

A specimen from the dike farthest from the quarry—and nearest to the great body of diabase—was examined by Dr. Whitman Cross, who reported that it was a gabbro.

> Its main constituents are augite and plagioclase, with a rude parallel arrangement of the minerals, suggesting that the specimen was derived from the neighborhood of an original dike contact. There is a small amount of brown amphibole, probably paramorphic after augite. While several joints are visible cutting the specimen, no actual shearing zones or planes were detected in the two sections prepared from this specimen.

Several specimens from the body of the "green slate" band, and also from the contact between the "green slate" band and the normal black clay-slates, were submitted to Dr. Cross for examination. The results of this study were unfortunately unconclusive. Dr. Cross states that the specimens are composed largely of feldspar, calcite, chlorite, and some other minerals. All are evidently greatly sheared. They present, however, no direct evidence of derivation from the kind of rock represented by the specimen from the dike near the tunnel entrance. They contain no augite or plagioclase, as such, and show no transition in texture. While it is quite possible that these rocks may have been derived from an igneous rock like the gabbro, such derivation is not shown by microscopic examination of the specimens submitted.

Chemical investigation.—A typical specimen of the green slate, from near the middle of the band, was selected for partial analysis in the laboratory of the U. S. Geological Survey, and the results of this analysis are presented below, as No. 1. The second analysis given below was quoted to the writer by Mr. C. H. Dunton, manager of the Eureka Slate Co., but the name of the analyst was unknown to him. The two analyses agree sufficiently closely, and are probably fairly representative of the chemical composition of the green slates.

ANALYSES OF THE "GREEN SLATES" FROM SLATINGTON, CALIF.

	1	2
Silica (SiO_2)	45.15	47.30
Alumina (Al_2O_3) and titanic oxide (TiO_2)	16.33	15.53
Iron oxides (FeO, Fe_2O_3)	8.42	8.00
Lime (CaO)	6.42	7.83
Magnesia (MgO)	8.72	7.86
Akalies (Na_2O, K_2O)	n. d.	3.17
Carbon dioxide (CO_2) Water	11.28	9.92

1. By W. T. Schaller, U. S. Geological Survey laboratory.
2. Analyst unknown. Analysis quoted by Eureka Slate Co.

It will be seen that these analyses differ widely from those of any normal clay slate, and even if no structural evidence were at hand, the chemical composition of the green slate would be sufficient to suggest that their origin was probably from igneous, not sedimentary, rocks.

For the purpose of indicating the class of rocks from which these green slates were probably derived, a number of analyses have been selected from Turner's papers[1] on the rocks of the Sierra Nevada, and these are presented below. The specimens analyzed were all from California localities, but none, unfortunately, from very near the El Dorado county slate deposits. None of the analyses are complete, but sufficient determinations are given in each case to permit their use for the present purpose—their comparison with the analyses, given above, of the green slate from Eureka Slate Co. quarry. The coincidence in general composition seems to be sufficiently marked to suggest, with a high degree of probability, that the green slates have been derived from some rock of type similar to those whose analyses are given in the following table:

ANALYSES OF IGNEOUS ROCKS OF THE MOTHER LODE DISTRICT, CALIFORNIA.

	1	2	3	4	5
Silica (SiO_2)	53.14	51.32	49.24	48.86	45.92
Alumina (Al_2O_3) and titanic oxide (TiO_2)	n. d.	15.28	14.79	n. d.	n. d.
Iron oxides (FeO, Fe_2O_3)	n. d.	9.06	9.52	n. d.	n. d.
Lime (CaO)	9.56	11.58	10.74	7.65	9.96
Magnesia (MgO)	4.97	7.25	6.89	9.88	13.85
Alkalies (K_2O, Na_2O)	3.29	3.14	3.64	4.82	0.81
Carbon dioxide (CO_2) Water	n. d.	n. d.	4.07	n. d.	n. d.

1. Gabbro: east side of Eureka Peak, California; analyzed by Hillebrand and Steiger. (*Seventeenth Annual Report*, U. S. Geological Survey, Part II, p. 642.)

2. Diabase: north of Hornitos, Calif.; analyzed by Hillebrand. (*Ibid.*, p. 694.)

3. Augite porphyrite: west of Jackson, Calif.; analyzed by Hillebrand and Steiger. (*Fourteenth Annual Report*, Part II, p. 473.)

4. Augite porphyrite: Plumas county, Calif.; analyzed by Hillebrand and Steiger. (*Ibid.*)

5. Gabbro: east of Penman Peak, Calif.; analyzed by Hillebrand and Steiger. (*Seventeenth Annual Report*, Part I, p. 642.)

Summary of the evidence as to the origin of the green slates.—An attempt has been made to obtain evidence from three distinct sources as to the probable derivation of the green slates. One of these possible lines of solution gave no evidence of value; the other two, however, are apparently conclusive.

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[1] *Fourteenth* and *Seventeenth Annual Reports*, U. S. Geological Survey.

1. The structural relations of the green and the black slates seem to prove that the green slates are derived, by dynamic metamorphism, from an igneous rock; further, that this rock was an intrusive massive rock, not an interbedded tuff; and that it was intruded into the Mariposa slates at some period subsequent to their deposition, but before their assumption of slaty cleavage.

2. Microscopic evidence, though inconclusive owing to the lack of a sufficient supply of material, proves that the green slates are composed of thoroughly crystalline material. The rock forming one of the nearby dikes is shown to be a gabbro.

3. Chemical analyses of the green slates show that they are widely different in composition from the black slates, and, indeed, from any normal clay slate. Comparison of the same analyses with those of igneous rocks of the region show striking similarities in composition between the green slates and certain massive, basic, igneous rocks—gabbros and allied rocks.

There are, of course, no reasons why an igneous rock should not be susceptible of change, under proper conditions, into a roofing slate; and the possibility of such a change occurring would probably have been conceded by most geologists, had the question been brought to their attention, before the foregoing description of an actual occurrence had been published. Notwithstanding these facts, the California occurrence seems to be unique. The extensive literature of roofing slate has been examined by the writer, so far as this literature is available, and no similar occurrences of the derivation of roofing slates from massive igneous rocks have been noted. More than this, the possibility of such an occurrence would seem to have been overlooked by most writers, who either expressly or by implication use the term "roofing slate" to include only argillaceous sedimentary rocks. This oversight is the more inexcusable, because a large industry has been based for a century or more, in one English district, on roofing slates derived from tuffs.

Utilization of the green slate.—While the green slate does not occur in a body of sufficient thickness to be worth quarrying for itself alone, it is a resource of considerable value as it is at present exposed in the quarry of the Eureka Slate Co. With the exception of the usual decomposed material near the ground surface, the green slate dike furnishes merchantable slate from the outcrop down to the tunnel level.

The green slate splits readily, though not with as smooth a surface as the black slate; and gives a pleasant color contrast when used for trimming or lettering on black slate roofs. It bears punching and countersinking very well, and is sufficiently strong for roofing use.

Compared with the large amount of merchantable black slate now in sight, the total quantity of green slate is so small that no attempt is being made to push its sale for use separately from the black slate. It is now supplied solely as an ornamental trimming for black slate roofs, for lettering, and similar uses.

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